The Case for a Super Neutrino Beam

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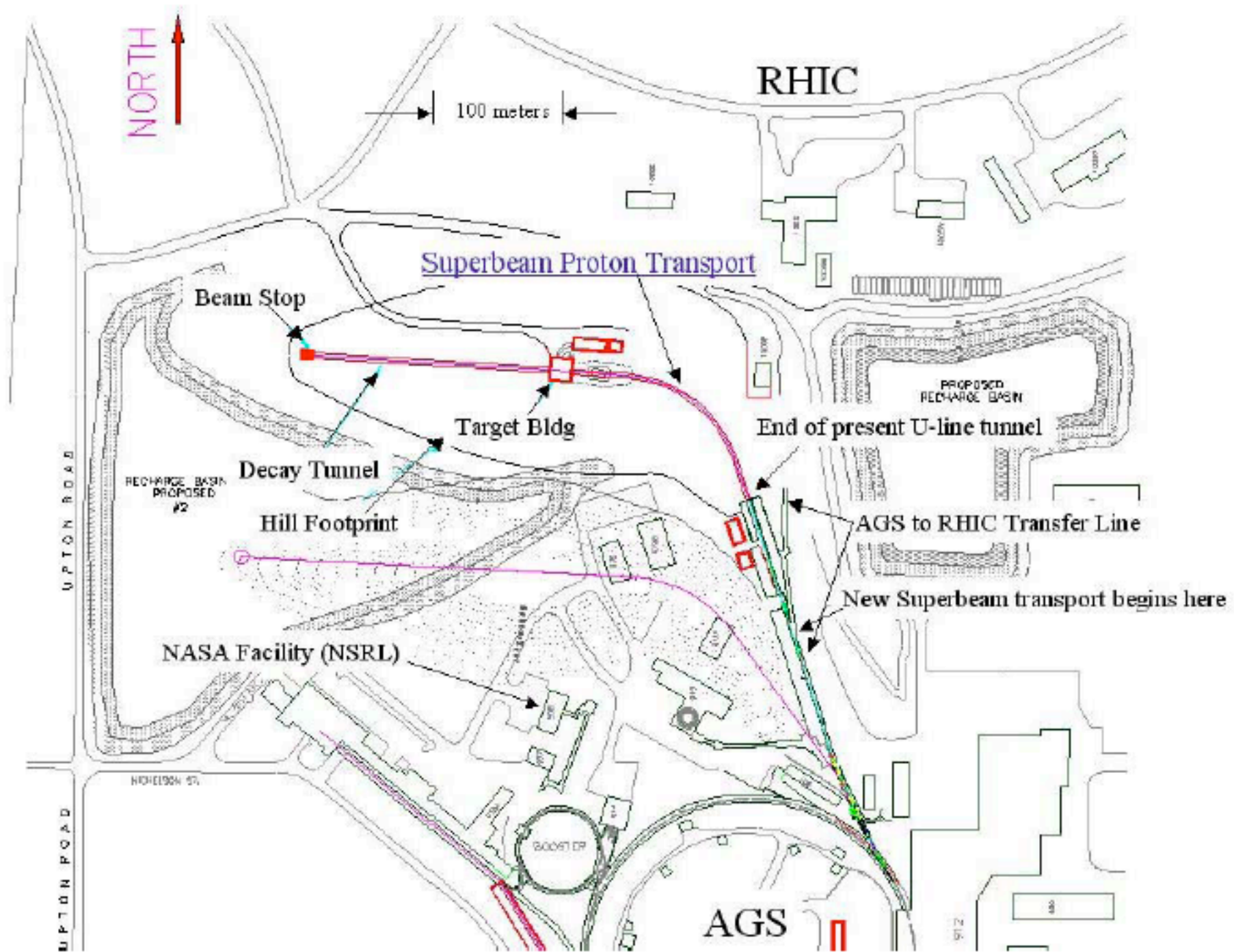# The Case for a Super Neutrino Beam

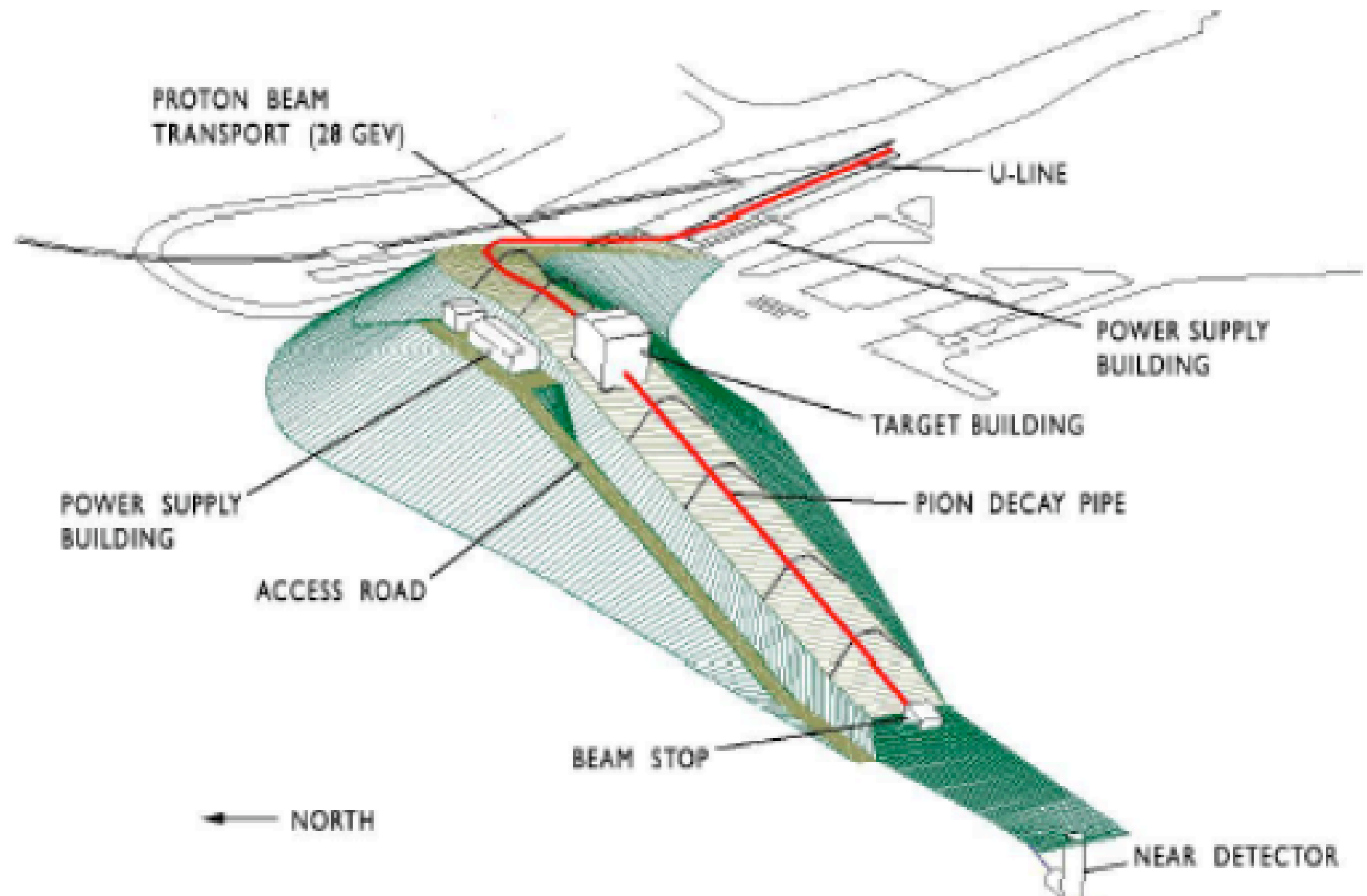Milind V. Diwan
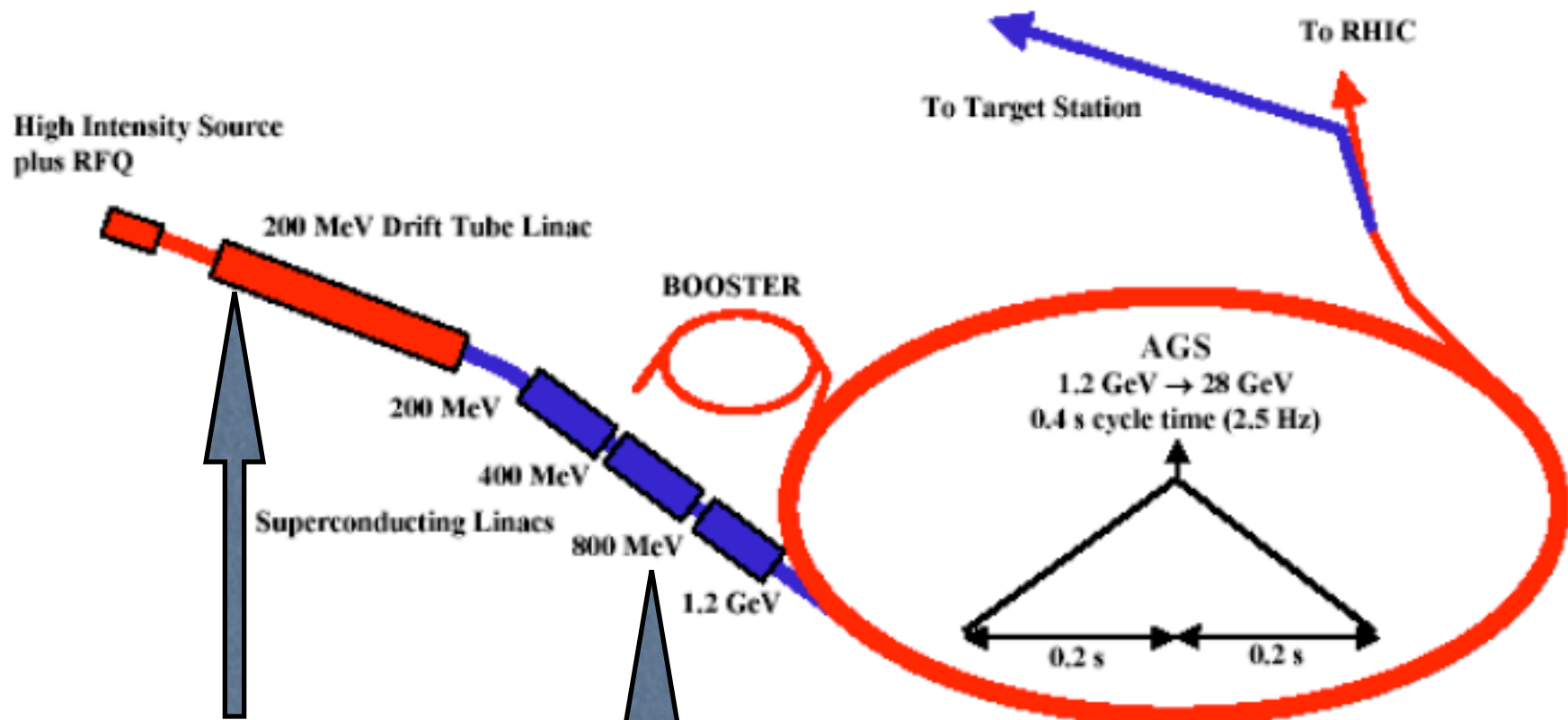*Brookhaven National Laboratory*

ABSTRACT

In this paper I will discuss how an intense beam of high energy neutrinos produced with conventional technology could be used to further our understanding of neutrino masses and mixings. I will describe the possibility of building such a beam at existing U.S. laboratories. Such a project couples naturally to a large (> 100 kT) multipurpose detector in a new deep underground laboratory. I will discuss the requirements for such a detector. Since the number of sites for both an accelerator laboratory and a deep laboratory are limited, I will discuss how the choice of baseline affects the physics sensitivities, the practical issues of beam construction, and event rates.

Update on AGS based Super Neutrino beam

- New conceptual design document BNL-73210-2004-IR. (sent to DOE)

- http://raparia.sns.bnl.gov/nwd_ad

- Redesigned beam facility: more compact, now possible to make decay pipe longer.

- Completely new design for injector LINAC: cheaper and faster to build.

PROTON BEAM TRANSPORT (28 GEV)

U-LINE

POWER SUPPLY BUILDING

TARGET BUILDING

PION DECAY PIPE

POWER SUPPLY BUILDING

ACCESS ROAD

BEAM STOP

NORTH

NEAR DETECTOR

High Intensity Source plus RFQ

200 MeV Drift Tube Linac

200 MeV

400 MeV

Superconducting Linacs

800 MeV

1.2 GeV

BOOSTER

To Target Station

To RHIC

AGS
1.2 GeV → 28 GeV
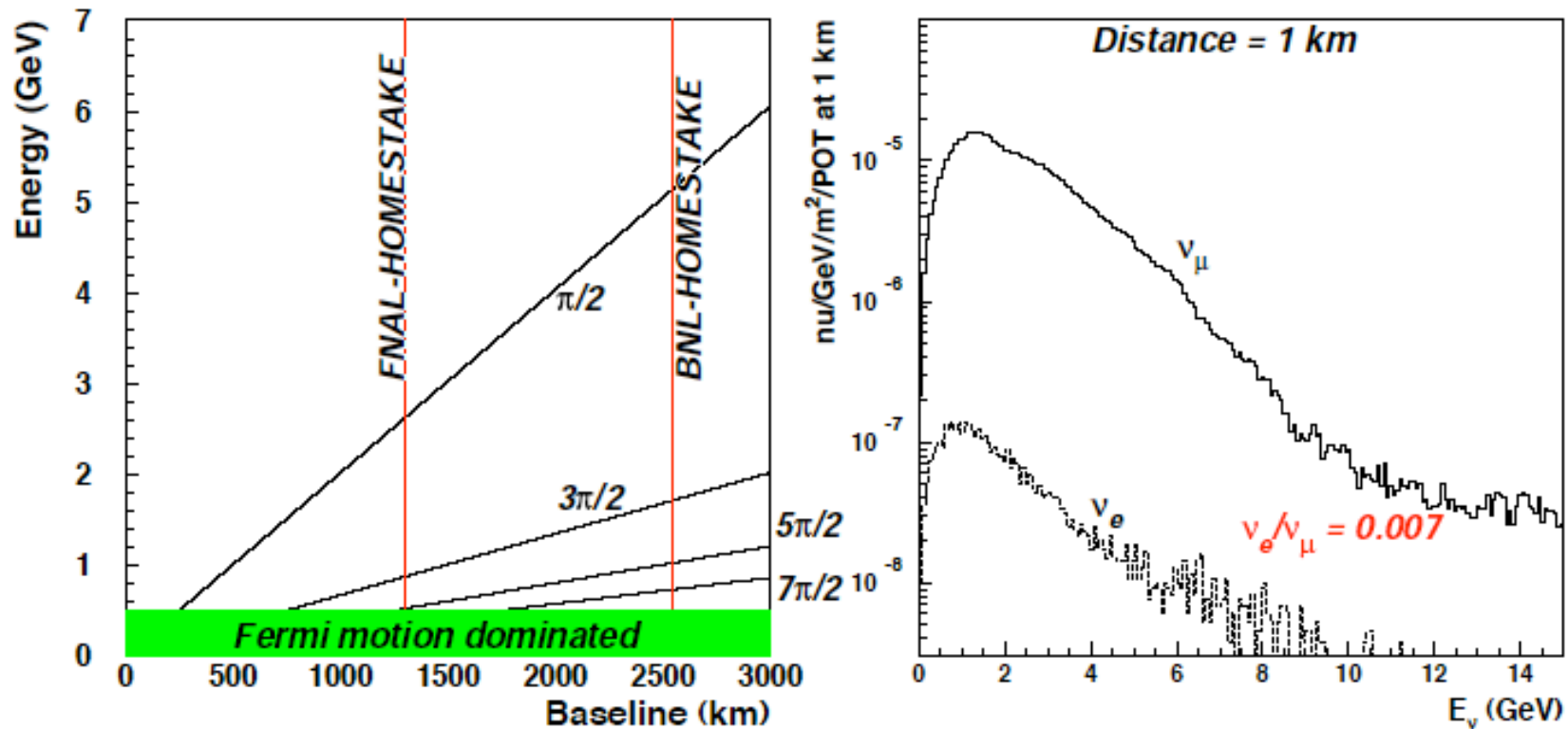0.4 s cycle time (2.5 Hz)

0.2 s   0.2 s

New idea: extend existing RTL to 400 MeV using a coupled cavity linac just like FNAL

Old: low beta: 805 MHz
medium high beta: 1610 MHz

New idea: after 400 MeV use 805 MHz all the way to ~1.5 GeV.
Use SNS design and get to higher energy

Back to Very Long Baselines

Oscillation Nodes for $\Delta m^2 = 0.0025$ eV^2 BNL Wide Band. Proton Energy = 28 GeV

Use same spectrum to study both baselines for this study. Comment on useful spectrum changes. Use 500 kT for both baselines with same performance.

Simple rules

- Multiples nodes important for precision and new physics.

- Long distances separate CP and matter effects.

- Need 2500 kT*MW*$(10^7 \, \text{sec})$ for measuring CP (regardless of distance and value of θ_{13})

- For CP violation study NO conventional beam experiment can get below $\sin^2 2\theta_{13} \sim 0.01$
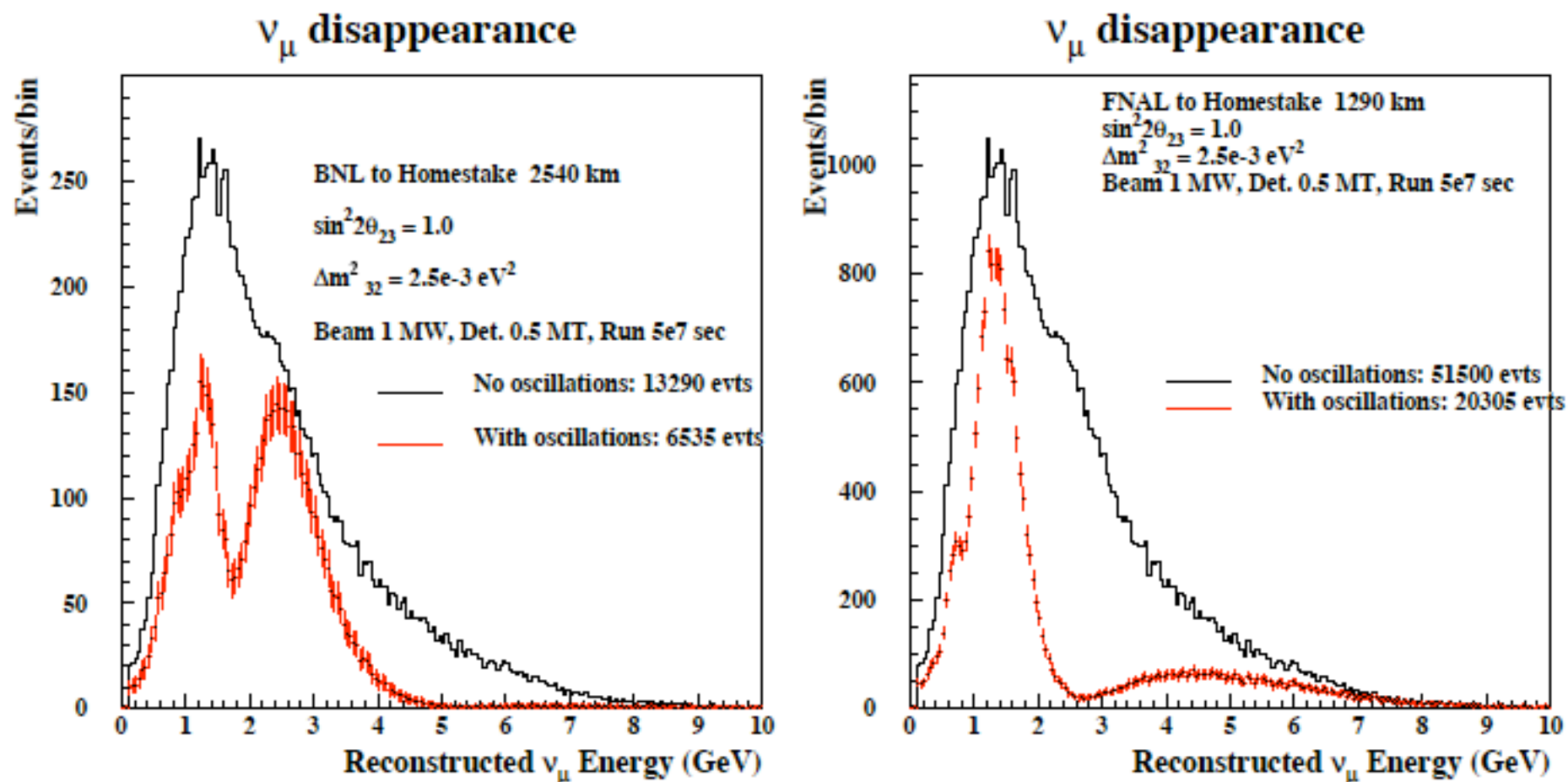
Figure 2: *Simulated spectrum of detected muon neutrinos for 1 MW beam and 500 kT detector exposed for 5×10^7 sec. Left side is for baseline of 2540 km, right side for baseline of 1290 km. The oscillation parameters assumed are shown in the figure. Only clean single muon events are assumed to be used for this measurement (see text).*
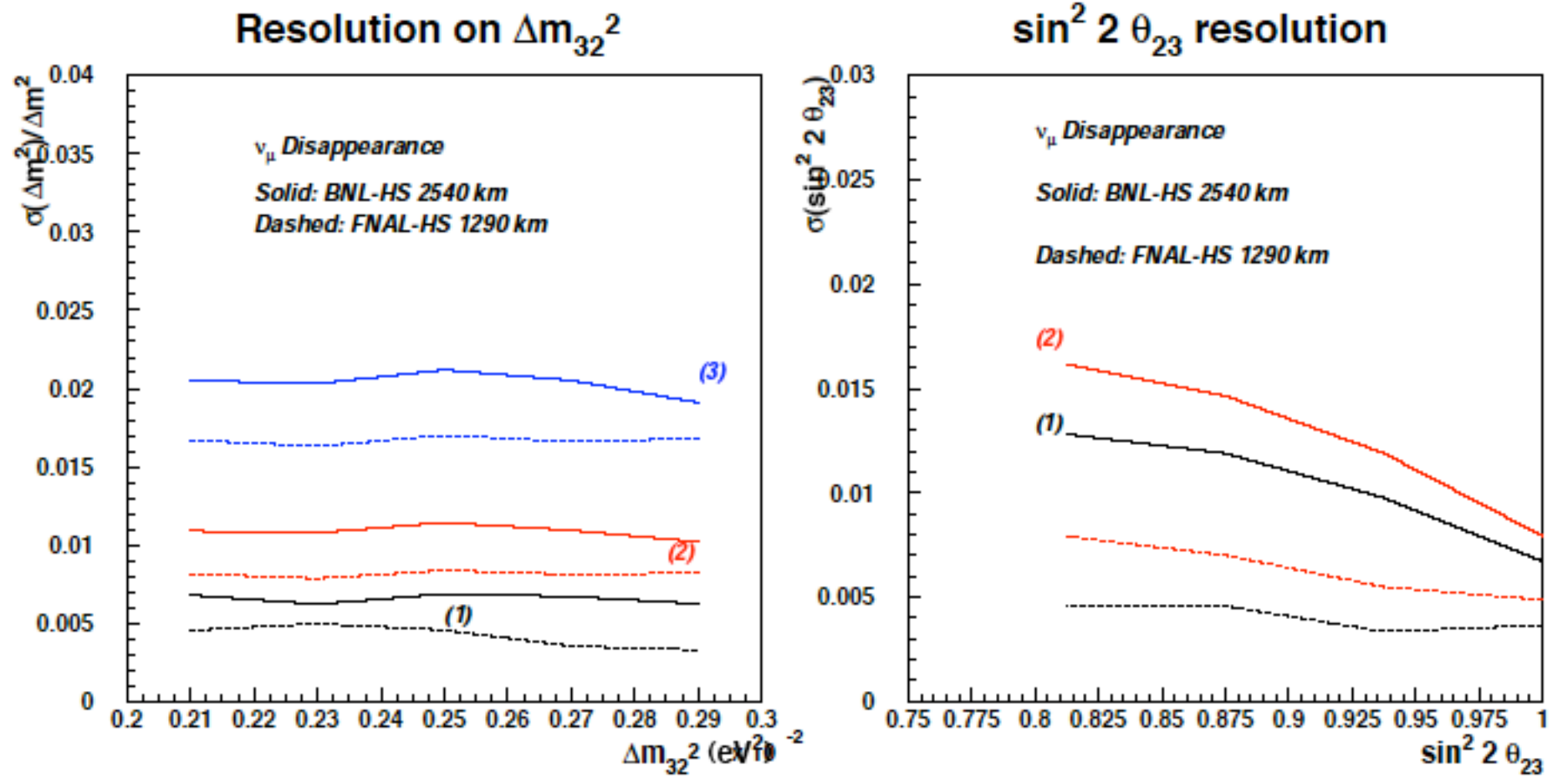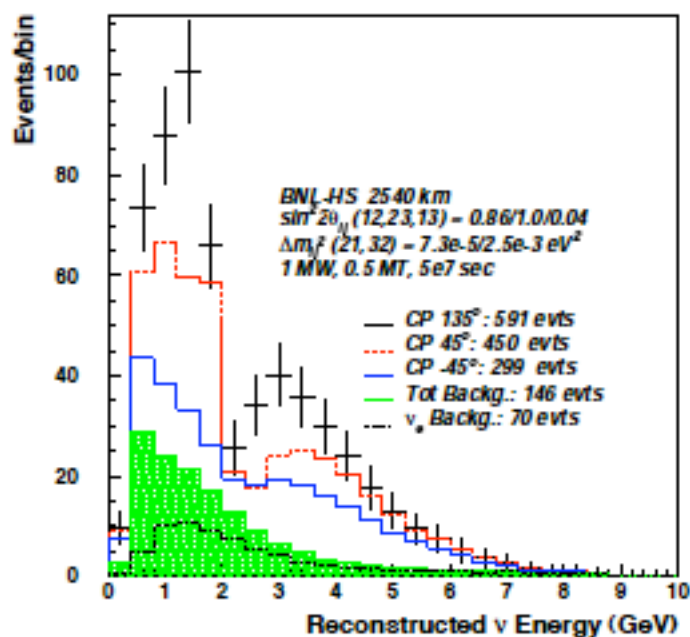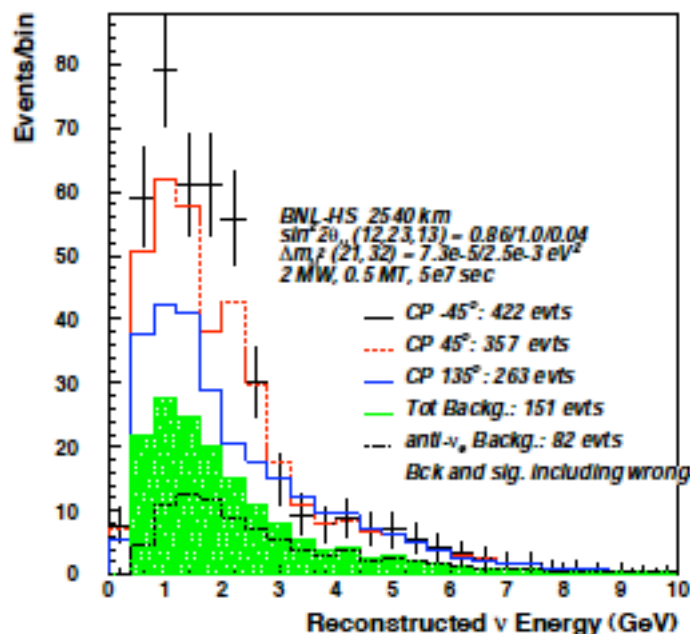
Figure 3: *1 sigma resolutions on Δm_{32}^2 (left) and $\sin^2 2\theta_{23}$ (right) expected after analysis of the oscillation spectra from Figure 2. The solid curves are for BNL-HS 2540 km baseline, and the dashed are for FNAL-HS 1290 km baseline. The curves labeled 1 and 2 correspond to statistics only and statistics and systematics, respectively (similarly for dashed curves of the same color). The curve labeled (3) on the left has an additional contribution of 1% systematic error on the global energy scale.*
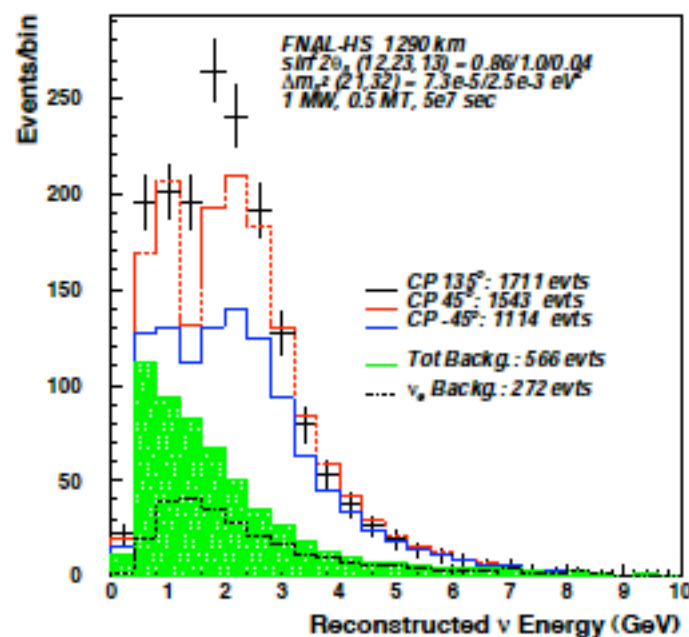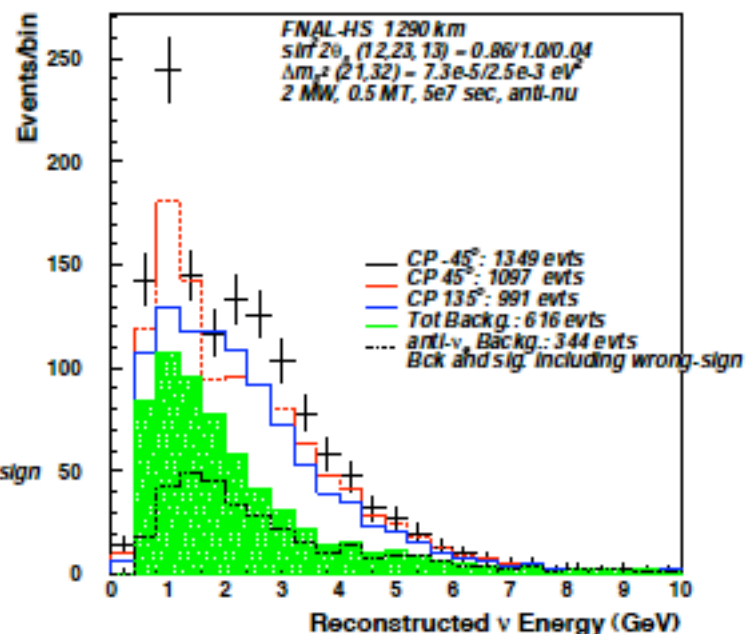
ν_e APPEARANCE

BNL-HS 2540 km
$\sin^2 2\theta_U$ (12,23,13) = 0.86/1.0/0.04
Δm_{ij}^2 (21,32) = 7.3e-5/2.5e-3 eV^2
1 MW, 0.5 MT, 5e7 sec

CP 135° : 591 evts
CP 45° : 450 evts
CP -45° : 299 evts
Tot Backg.: 146 evts
ν_e Backg.: 70 evts

ν_e APPEARANCE

FNAL-HS 1290 km
$\sin^2 2\theta_U$ (12,23,13) = 0.86/1.0/0.04
Δm_{ij}^2 (21,32) = 7.3e-5/2.5e-3 eV^2
1 MW, 0.5 MT, 5e7 sec

CP 135° : 1711 evts
CP 45° : 1543 evts
CP -45° : 1114 evts
Tot Backg.: 566 evts
ν_e Backg.: 272 evts

AntI-ν_e APPEARANCE

BNL-HS 2540 km
$\sin^2 2\theta_U$ (12,23,13) = 0.86/1.0/0.04
Δm_{ij}^2 (21,32) = 7.3e-5/2.5e-3 eV^2
2 MW, 0.5 MT, 5e7 sec

CP -45° : 422 evts
CP 45° : 357 evts
CP 135° : 263 evts
Tot Backg.: 151 evts
anti-ν_e Backg.: 82 evts
Bck and sig. including wrong-sign

AntI-ν_e APPEARANCE

FNAL-HS 1290 km
$\sin^2 2\theta_U$ (12,23,13) = 0.86/1.0/0.04
Δm_{ij}^2 (21,32) = 7.3e-5/2.5e-3 eV^2
2 MW, 0.5 MT, 5e7 sec, anti-nu

CP -45° : 1349 evts
CP 45° : 1097 evts
CP 135° : 991 evts
Tot Backg.: 616 evts
anti-ν_e Backg.: 344 evts
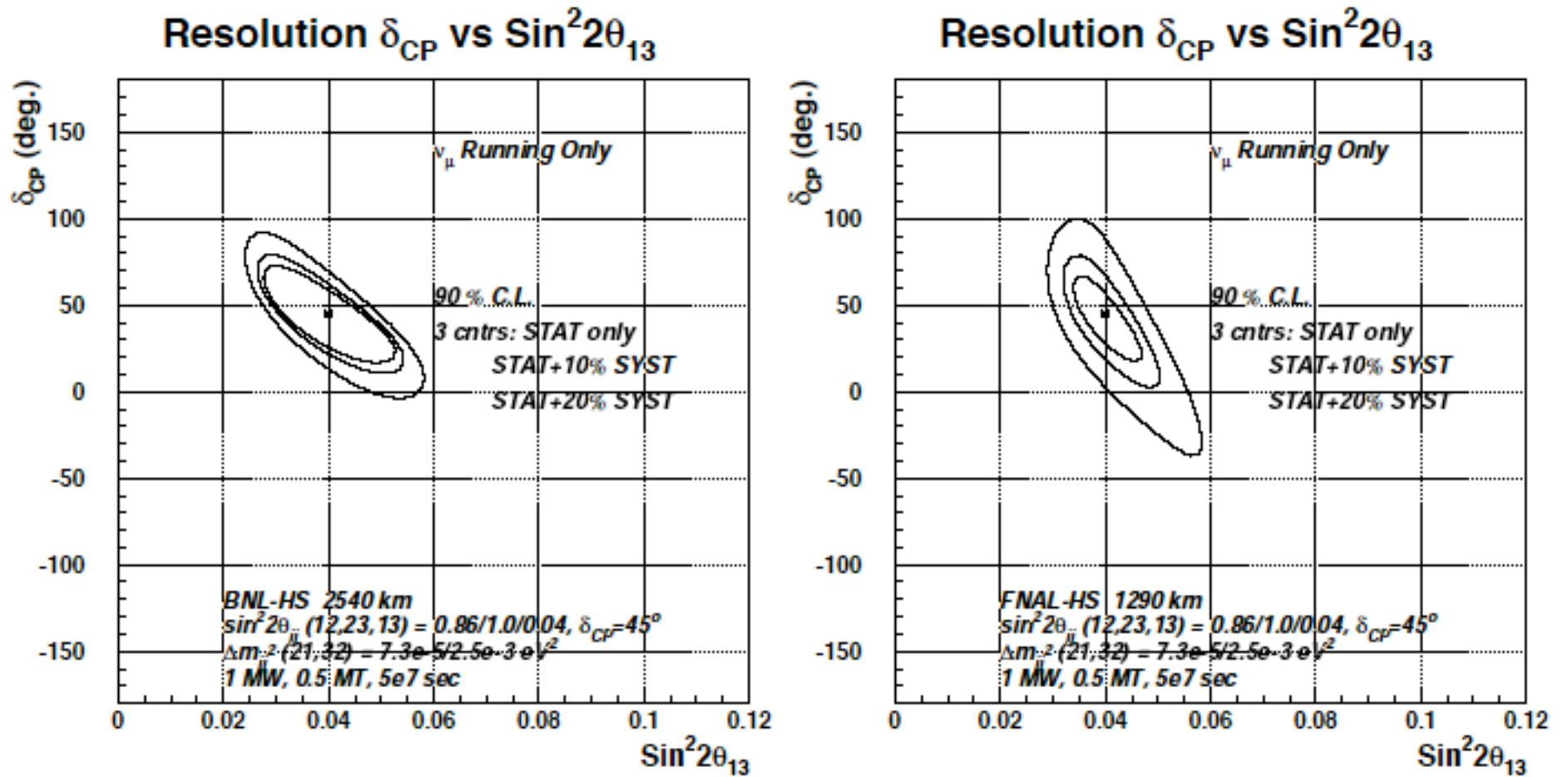Bck and sig. including wrong-sign

Figure 6: *90% confidence level error contours in* $\sin^2 2\theta_{13}$ *versus* δ_{CP} *for statistical and systematic errors with neutrino data alone. Left is for BNL-HS and right is for FNAL-HS. The test point used here is* $\sin^2 2\theta_{13} = 0.04$ *and* $\delta_{CP} = 45^o$. $\Delta m_{32}^2 = 0.0025 \ eV^2$, *and* $\Delta m_{21}^2 = 7.3 \times 10^{-5} \ eV^2$. *The values of* $\sin^2 2\theta_{12}$ *and* $\sin^2 2\theta_{23}$ *are set to 0.86, 1.0, respectively.*
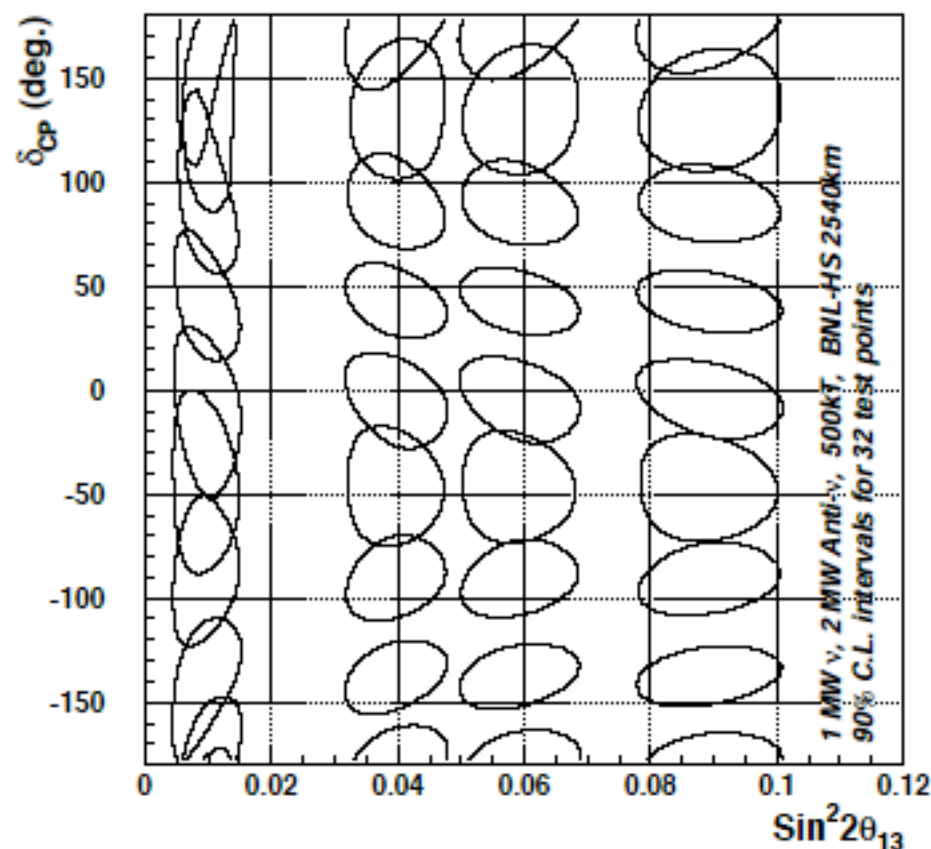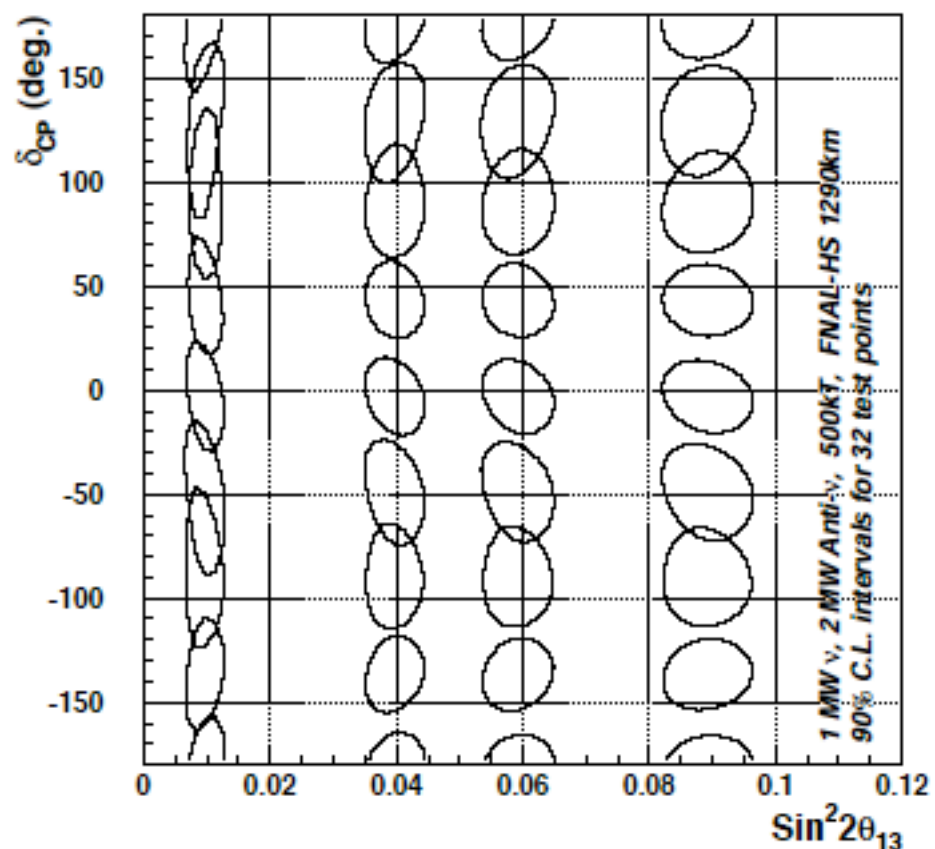
Regular hierarchy ν and Antiν running   **Regular hierarchy ν and Antiν running**

Figure 7: *90% confidence level error contours in* $\sin^2 2\theta_{13}$ *versus* δ_{CP} *for statistical and systematic errors for 32 test points. This simulation is for combining both neutrino and anti-neutrino data. Left is for BNL-HS and right is for FNAL-HS. We assume 10% systematic errors for this plot.*
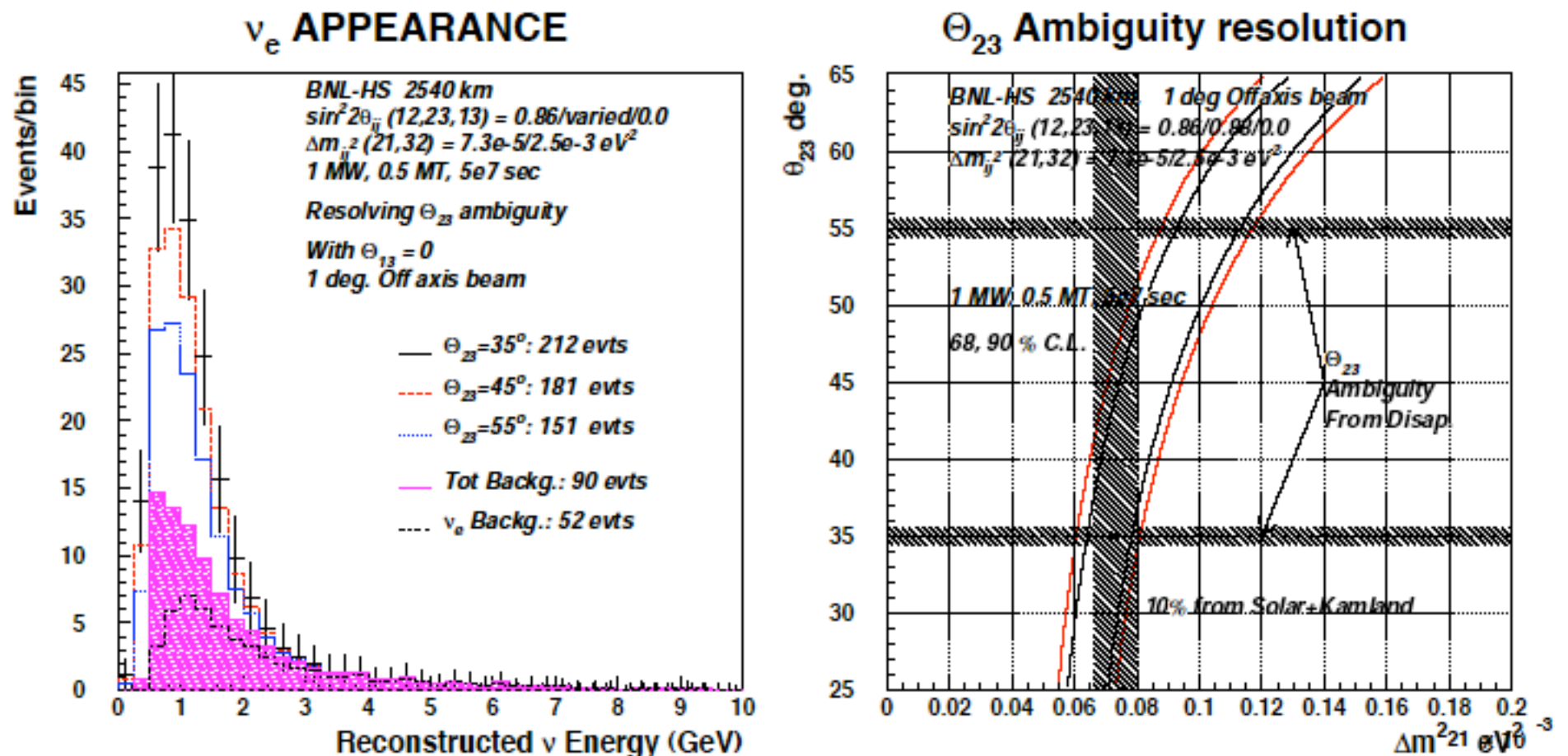
Figure 8: *Expected spectrum of electron neutrinos (left) for $\theta_{13} = 0$ and other assumed parameters indicated in the figure. The right hand side shows the resolution of the $\theta_{23} \rightarrow \pi/2 - \theta_{23}$ ambiguity using the measurement of $\sin^2 2\theta_{23}$ from disappearance and assuming a 10% measurement of Δm^2_{21} from KAMLAND. The area between the curves is allowed by the appearance spectrum (left) for $\theta_{23} = 35^o$.*

Conclusion

- Shorter baseline somewhat better for measuring mixing angles.

- CP phase measurement statistically indep of distance, but better at longer distance because systematic errors less important.

- With longer distance can get CP phase with neutrino running alone.

- Longer distance better for solar effect and resolving th23 ambiguity.

- Eventually have to couple to DUSEL 1 MT det.